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(54) Title: METHOD AND APPARATUS FOR POWER CONTROL IN A TELEPHONE SYSTEM			
<pre> graph LR AN[ACCESS NETWORK] --- BS[BASE STATION] BS --- 3.5 GHz NTE1[SUBSCRIBER UNIT NTE1] BS --- 3.5 GHz NTE2[SUBSCRIBER UNIT NTE2] BS --- 3.5 GHz NTE3[SUBSCRIBER UNIT NTE3] NTE1 --- TE1[TERMINAL EQUIP TE] NTE2 --- TE2[TE] NTE3 --- TE3[TE] TC[TEST CALLS] -.-> NTE1 TC -.-> NTE2 TC -.-> NTE3 </pre>			
(57) Abstract <p>In apparatus and a method of transmitting messages in predetermined time slots within fixed length time frames, during a call a target power level of transmission is set by a second unit, the second unit is operative to measure the power level of a received message and to send a power level control signal to a first unit to adjust the power level of transmission during the call, the control signal being dependent upon the measured power level, and in which the power level of messages sent by the first unit at the start of a call is set dependent upon the power levels of messages sent by the first unit in previous successful calls to the second unit.</p>			

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METHOD AND APPARATUS FOR POWER CONTROL IN A TELEPHONE SYSTEM

The present invention relates to controlling power transmitted from a first transmitting and receiving unit to a second transmitting and receiving unit, in particular where units are at fixed locations.

Automatic power control is known and used widely in mobile GSM networks, in particular, being described in GSM specifications 05.05 and 05.08. In GSM networks, automatic power control is used to control the power transmitted from each mobile station and, optionally, can be used to control power transmitted from the base station. In GSM, automatic power control is used to reduce the level of power transmitted. An indicator of the initial transmit power to be used by the mobile station is sent in a message from the base station and the mobile station complies with this message.

The present invention provides a method of transmitting messages in predetermined time slots within fixed length time frames between a first transmitting and receiving unit and a second transmitting and receiving unit in which during a call a target power level of transmission is set by the second unit, the second unit is operative to measure the power level of a received message and to send a power level control signal to the first unit to adjust the power level of transmission during the call, the control signal being dependent upon the measured power level, and in which the power level of messages sent by the first unit at the start of a call is set dependent upon the adjusted power levels of messages sent by the first unit in previous successful calls to the second unit. The present invention also relates to corresponding apparatus.

Preferably a target power level is set by the second unit, the second unit being operative to measure the power level of a received message and to send a power level control signal to the first unit, the control signal being dependent upon the measured power level. Measurement and adjustment can continue automatically until the power received by the second unit meets the target power level, preferably within a predetermined tolerance measurement continues. Subsequently if there is variation in the received power at the second unit, the adjustment restarts.

Alternatively, the transmit power level can be set by the first unit itself dependent upon information of the power levels of previous successful calls. This is particularly useful for sending call set-up requests, system control messages and short messages to the second unit.

Preferably, a power level adjustment to decrease the transmit power level is only made provided interference is below a predetermined threshold.

The first unit is preferably a base station, and the second is preferably one of a plurality of subscriber units. Subscriber units are preferably at fixed locations. Transmissions are preferably by radio.

The received messages can be test calls. Where the first unit is a subscriber unit, test calls do not involve the user of the subscriber unit and can be made sufficiently frequently to keep the transmit power of a subscriber unit at an optimum level. Target power level can be set by the second unit using test calls.

Test calls can be made at any or all of the RF carrier frequencies available to a subscriber unit. Test calls can be made upon installation of the subscriber unit in the network.

Subscriber units can be categorised according to the propagation characteristics, such as path loss, which they experience. The frequency of test calls and/or size of ranges to be applied in determining whether power adjustments are required can be selected dependent on the categorisation given.

The present invention also relates to communication means comprising a base station and a plurality of subscriber units, the base station communicating with each subscriber unit by sending and receiving messages in predetermined time slots within fixed length time frames, in which during a call a target power level of transmission is set by the base station, the base station is operative to measure the power level of a received message and to send a power level control signal to the subscriber unit to adjust the power level of transmission during the call, the control signal being dependent upon the measured power level, and in which power level for messages sent by a subscriber unit at the start of a call is set dependent on the adjusted power levels of messages previously sent by that subscriber unit and received by the base station.

In a second aspect the present invention also provides method of transmitting messages in predetermined time slots within fixed length time frames between a first transmitting and receiving unit and a second transmitting and receiving unit in which the second unit is operative to measure the power level of a received message and to determine the level of interference due to other second units communicating with first units, said second unit

interference due to other second units communicating with first units, said second unit being operative to send a power level adjustment signal to the first unit dependent upon the measured power level, to increase or decrease the power level, a power decrease signal being sent and/or a power decrease being effected provided the interference level is determined as being below a predetermined threshold.

The present invention also relates to corresponding apparatus.

A first unit is preferably a subscriber unit. The second unit(s) are preferably base station(s).

The present invention in a second aspect also relates to communication means comprising a base station and a plurality of subscriber units, the base station communicating with each subscriber unit by sending and receiving messages in predetermined time slots within fixed length time frames, in which the base station is operative to measure the power level of a received message from a subscriber unit and to determine the level of interference due to subscriber units communicating with other base stations, the power levels for messages sent by said subscriber unit being reduced dependent on the power level of the received message provided the level of interference is below a predetermined threshold.

A preferred embodiment of the invention will now be described, by way of example, with reference to the drawings in which:

Figure 1 is a schematic diagram illustrating the system including a base station (BTE -

Base Terminating Equipment) and subscriber unit (NTE - Network Terminating Equipment);

Figure 2 is a diagram illustrating frame structure and timing for a duplex link;

Figure 3 is a further schematic diagram illustrating the system;

Figure 4 is a schematic graph illustrating power level tolerances applied over time;

Figure 5 is a graphical representational of one example of power level detection and adjustment;

Figure 6 is a schematic graph illustrating categorisation of subscriber units;

Figure 7 is a schematic topology of part of the preferred network showing four cells each having a base station and subscriber units.

Basic System

As shown in Figure 1, the preferred system is part of a telephone system in which the local wired loop from exchange to subscriber has been replaced by a full duplex radio link between a fixed base station and fixed subscriber unit. The preferred system includes the duplex radio link, and transmitters and receivers for implementing the necessary protocol. There are similarities between the preferred system and digital cellular mobile telephone

systems such as GSM which are known in the art. This system uses a protocol based on a layered model, in particular the following layers; PHY (Physical), MAC (Medium Access Control), DLC (Data Link Control), NWK (Network).

One difference compared with GSM is that, in the preferred system, subscriber units are at fixed locations and there is no need for hand-off arrangements or other features relating to mobility. This means, for example, in the preferred system directional antennae and mains electricity can be used.

Each base station in the preferred system provides six duplex radio links at twelve frequencies chosen from the overall frequency allocation, so as to minimise interference between base stations nearby. The frame structure and timing for the duplex link is illustrated in Figure 2. Each duplex radio link comprises an up-link from a subscriber unit to a base station and, at a fixed frequency offset, a down-link from the base station to the subscriber unit. The down-links are TDM, and the up-links are TDMA. Modulation for all links is $\pi/4$ - DQPSK, and the basic frame structure for all links is ten slots per frame of 2560 bits i.e. 256 bits per slot. The bit rate is 512kbps. Down-links are continuously transmitted and incorporate a broadcast channel for essential system information. When there is no user information to be transmitted, the down-link transmissions continue to use the basic frame and slot structure and contain a suitable fill pattern.

For both up-link and down-link transmissions, there are two types of slot: normal slots which are used after call set-up, and pilot slots used during call set-up.

Each down-link normal slot comprises 24 bits of synchronisation information followed by 24 bits designated S-field which includes an 8 bit header, followed by 160 bits designated D-field. This is followed by 24 bits of Forward Error Correction and an 8 bit filler, followed by 12 bits of the broadcast channel. The broadcast channel consists of segments in each of the slots of a frame which together form the down-link common signalling channel which is transmitted by the base station, and contains control messages containing link information such as slot lists, multi-frame and super-frame information, connectionless messages and other information basic to the operation of the system.

During call set-up, each down-link pilot slot contains frequency correction data and a training sequence for receiver initialisation, with only a short S-field and no D-field information.

Up-link slots basically contain two different types of data packet. The first type of packet, called a pilot packet, is used before a connection is set up, for example, for an ALOHA call request and to allow adaptive time alignment. The other type of data packet, called a normal packet, is used when a call has been established and is a larger data packet, due to the use of adaptive time alignment.

Each up-link normal packet contains a data packet of 244 bits which is preceded and followed by a ramp of 4 bits duration. The ramps and the remaining bits left of the 256 bit slot provide a guard gap against interference from neighbouring slots due to timing errors. Each subscriber unit adjusts the timing of its slot transmissions to compensate for the time it takes signals to reach the base station. Each up-link normal data packet

comprises 24 bits of synchronisation data followed by an S-field and D-field of the same number of bits as in each down-link normal slot.

Each up-link pilot slot contains a pilot data packet which is 192 bits long preceded and followed by 4 bits ramps defining an extended guard gap of 60 bits. This larger guard gap is necessary because there is no timing information available and without it propagation delays would cause neighbouring slots to interfere. The pilot packet comprises 64 bits of sync followed by 104 bits of S-field which starts with an 8 bit header and finishes with a 16 bit Cyclic Redundancy Check, 2 reserved bits, 14 FEC bits, and 8 tail bits. There is no D-field.

The S-field in the above mentioned data packets can be used for two types of signalling. The first type is MAC signalling (MS) and is used for signalling between the MAC layer of the base station and the MAC layer of a subscriber unit whereby timing is important. The second type is called associated signalling, which can be slow or fast and is used for signalling between the base station and subscriber units in the DLC or NWK layers.

The D-field is the largest data field, and in the case of normal telephony contains digitised speech, but can also contain non-speech data samples.

Provision is made in the preferred system for subscriber unit authentication using a challenge response protocol. General encryption is provided by combining the speech or data with a non-predictable sequence of cipher bits produced by a key stream generator which is synchronised to the transmitted super-frame number.

In addition, the transmitted signal is scrambled to remove dc components.

Automatic Power Control

A typical topology of base stations/subscriber units is shown in Figure 3. Automatic Power Control operates in the following manner for all MAC channels. At the start-up of a call connection made at the MAC layer, the subscriber unit begins transmitting at a predetermined power (see below). The received power at a base station is measured and adjustment commands sent to the subscriber unit. The subscriber unit responds to these commands by changing its transmit power by the increment suggested by the base station. The base station measures the received power for the duration of the call and sends appropriate commands to the subscriber unit.

At start-up of a connection at the MAC level, the base station measures the received signal strength of transmissions from a particular subscriber unit for a short period (0.25s). This gives a measurement the accuracy of which depends on the propagation conditions but is typically not expected to be greater than the largest range (threshold j) as shown in figure 4. If the received signal strength lies outside this range ($\pm j$) then the base station commands the subscriber unit to alter its transmit power.

Subsequently, a longer measurement period is used to provide a more accurate measurement of the mean received signal strength. Again, if the received signal strength lies outside the $\pm k$ range then the base station commands a change in transmit power from the subscriber unit. The third measurement period is the one used in all subsequent

measurements and allows the most accurate measurement of mean received power. If the transmit power moves outside the $(+/-n)$ range then the base station will command the subscriber unit to alter its transmit power.

A typical process including each of the three above thresholds is illustrated in figure 5. This shows the case where the first 0.25s measurement of base station received signal strength is outside the $(+/-j)$ range and as a consequence a first power change command is sent which adjusts the subscriber unit transmit power such that the signal strength received at the base station is within the $(+/-k)$ range but not the $(+/-n)$ range. A further power change command results after the third measurement period should the mean received signal strength lie outside the $(+/-n)$ range.

Determination of Initial Power level for transmissions at a Subscriber Unit

In the preferred network, calculation of initial transmit power is performed in the subscriber unit using information from several eg. four or five previous calls. This is possible because, in the preferred network, the subscriber units are fixed. Automatic power control in the preferred embodiment of the present invention optimises power levels by increasing as well as reducing transmit power from a subscriber unit.

There are special procedures operating in the subscriber unit for determining the correct power to be used at initialisation of either a call set-up request or a system control message. This is the power which is set by the subscriber unit before any control messages from the base station have been transmitted, for example, to adjust the power level. The

initial transmit power is determined at the subscriber unit based on the history of a number of calls on a particular RF carrier frequency. For each RF carrier frequency, initial transmit power is stored such that it is possible to set a different transmit power from the subscriber unit for each RF carrier frequency that could be used.

During the period for which a MAC connection is active, periodic power measurements are made by the subscriber unit so as to determine its own power setting. These are performed at the same rate as transmit power update signals are received from the base station. Each power measurement is used to update a running mean value of the transmit power. On deestablishment of a MAC connection, the current value of the running mean is used to update the initial transmit power value stored by the subscriber unit. The update is weighted by the number of previous MAC connections that are considered. For example, if a 5 call history is used then each update contributes 1/5 of its value to the initial transmit power setting. Each RF carrier signal has an associated initial transmit power value stored in respect of it. Each update will therefore only affect signals at the RF frequency on which the MAC connection was established.

Control of ranges applied in Automatic Power Control dependent on expected propagation characteristics

RF propagation characteristics between subscriber units and the base station can vary widely. In general, the standard deviation of variation in received signal strength increases with path loss (which in turn is loosely related to distance from the base station). Therefore, subscriber unit installations with high path loss exhibit greater variations in

signal strength than those with lower path losses. This is illustrated in figure 6, where subscriber unit NTE 1 has a lower path loss variation than subscriber unit NTE 2 which has the worst. (In Figure 6, S.D. denotes the standard deviation of path loss measurements). In the preferred power level control process which is used the population of subscriber units are divided into 12 possible path loss types, based on (i) fading frequency, (ii) fade depth and (iii) signal stability. Three of these types are denoted A, B and C in Figure 6. This classification is used to control two characteristics, namely (a) the convergence thresholds to be applied in determining whether a received signal has acceptable strength and (b) how often test calls are required (see below).

The convergence thresholds are the $\pm j$, k and n ranges described previously. These ranges are chosen dependent on path loss type such that the subscriber units operating with the highest channel stability and least fade depth are given tighter tolerances than subscriber units with lesser stabilities and greater fade depths.

Automatic Power Control using Test Calls

The initial transmit power from a subscriber unit is controlled using call history i.e. information of the power level acceptable for previous successful calls, as has already been discussed. It is important that customer calls are not relied upon for this process as they might well be too infrequent or old to be accurate. This could be for a number of reasons, for example, where customer is a low user or the customer is away on vacation for a long time. If no calls are made to the subscriber unit for long periods then it is possible for the initial transmit power setting to become outside the limits of what is currently acceptable.

This could cause unsatisfactory levels of interference to other subscriber units and, in the worst case, could prevent subscriber units from communicating with the base station.

Test calls are made from the base station to each subscriber unit communicating with the base station. A test call involves radio transmission using a TDMA scheme between base station and subscriber unit but does not involve communications to a telephone exchange nor does it result in any substantial processing activity at the subscriber unit. For example, the subscriber unit can still be used to make a PSTN call while a test call is in progress. The length of the test call is selected to allow for a statistically-accurate measurement of the mean received signal strength to be made. This in turn ensures that the adjustments made to the subscriber unit transmit power will be optimum for the prevailing propagation conditions.

In communicating with subscriber units, the base station periodically sends information specific to each subscriber unit of which RF carrier frequencies are:

- (i) preferred (the so-called 'white' channels)
- (ii) to be used if a preferred rf frequency is not available (the so-called 'grey' channels)
- (iii) not to be used (the so-called 'black' channels).

Each subscriber unit stores this information.

RF frequencies are categorised as 'black' if, for example, their use by a subscriber unit in

one sector of the network cell around a base station is likely to cause interference with transmissions from subscriber units in neighbouring sectors, RF frequencies are categorised as 'grey' where they provide poor quality but acceptable propagation.

Each subscriber unit maintains a Classified Carrier-List corresponding to the information received from the base station indicating radio frequencies that are preferred ("white"), frequencies that are only to be used due to the poor quality they provide if no preferred slot is available ("grey"), and frequencies which are not to be used ("black").

Test calls as described above are made upon installation of a subscriber unit, and at regular intervals to each subscriber unit, on each RF carrier marked as white or grey in the classified carrier list. This ensures that the initial transmit power of the subscriber unit is up to date thereby reducing the risk of no RF carrier frequency being available for a call due to RF propagation conditions.

This repetition rate of test calls to individual subscriber units is determined by considering the type classification applied to a particular subscriber unit, as described above. For example, subscriber units suffering poor propagation conditions are subject to more frequent test calls.

The test call scheduling is designed such that 12 separate test call schedules are specified with each subscriber unit communicating with a base station being assigned one of the 12 schedules.

At least one test call on each RF carrier frequency at each subscriber unit is attempted within the repeat period. For example, a subscriber unit classified as a type with good propagation characteristics may be assigned to a schedule of a test call every 47 hours whereas one classified as a type having poor propagation characteristics may have a test call schedule involving test calls every 4 hours.

Interference during Active Power Control

There are two types of interference; co-channel interference and adjacent channel interference as described below. A typical cellular topography is illustrated in Figure 7. The reference cell is that containing base station BTE 1. The available frequencies are divided into a number of subsets, denoted fs_1 , fs_2 , fs_3 .

Co-Channel Interference: Cells containing base station BTE 1 and base station BTE 4 operate with the same frequency set. Transmissions from subscriber unit NTE 1 to base station BTE 1 result in co-channel interference to base station BTE 4. The exact level of interference depends on the path loss between the two cells. Nevertheless, minimising the transmit power from subscriber unit NTE 1 minimises the level of uplink interference present at base station BTE 4.

Adjacent Channel Interference: Cells containing base stations BTE 1, BTE 2 and BTE 3 have mutually independent frequency sets, denoted fs_1 , fs_2 and fs_3 respectively. Each frequency set consists of a number of selected frequencies denoted fn where n increases with increasing frequency. However, optimum usage of the available frequency sets will

involve base stations BTE 1, BTE 2 and BTE 3 having adjacent frequencies present in the frequency sets (i.e. if selected rf frequency denoted n is used at base station BTE 1 then selected rf frequency denoted $n \pm 1$ would be used by base station BTE 2 or BTE 3). Interference is possible if the power transmitted by subscriber unit NTE 1 in adjacent channels ($n \pm 1$ using the notation above) is not sufficiently attenuated and the path loss between subscriber unit NTE 1 and either base station BTE 2 or base station BTE 3 is low. Again this effect can be mitigated by ensuring that subscriber unit NTE 1 is transmitting at no more than near minimum power for successful reception.

Automatic power control involves measuring the received power level of a transmitting subscriber unit at the receiving base station over a predetermined time interval to determine the power adjustment required. Should interference occur then the measured power would be increased leading to control signals being sent to reduce the transmit power level of the subscriber unit. This overcompensation is avoided by measuring the level of interference, and only making downward adjustments to transmit power provided the interference level is below a predetermined threshold. When the interference level is too high, the base station is inhibited from sending a power decrease signal.

The level of interference is measured by determining received signal quality relative to received signal strength. Quality is determined by monitoring errors in received data, in particular by comparing expected and received Forward Error Correction (FEC) data or Cyclic Redundancy Check (CRC) data; or by evaluation of RMS vector error. Vector Error is a vector estimate of difference between an expected and received symbol amplitude and phase. Vector errors for all symbols in a slot are stored and integrated to

provide the Root Mean Squared (RMS) Vector Error. RMS Vector Error is a scalar quantity.

CLAIMS

1. A method of transmitting messages in predetermined time slots within fixed length time frames between a first transmitting and receiving unit and a second transmitting and receiving unit in which during a call a target power level of transmission is set by the second unit, the second unit is operative to measure the power level of a received message and to send a power level control signal to the first unit to adjust the power level of transmission during the call, the control signal being dependent upon the measured power level, and in which the power level of messages sent by the first unit at the start of a call is set dependent upon the adjusted power levels of messages sent by the first unit in previous successful calls to the second unit.
2. A method of transmitting messages according to claim 1, in which the adjusted power levels of the previous N calls are averaged to provide the power level of messages sent by the first unit at the start of a call, N being an integer.
3. A method of transmitting messages according to claim 2, in which N is four.
4. A method of transmitting messages according to any preceding claim, in which steps of measurement of received power level and adjustment of power level of transmission are repeated until the power received by the second unit meets the target power level within a predetermined tolerance.
5. A method of transmitting messages according to claim 4 in which measurement continues automatically thereafter.

6. A method of transmitting messages according to claim 5, in which if there is variation in the measured received power beyond the predetermined tolerance, adjustment restarts.
7. A method of transmitting messages according to any of claims 1 to 6, in which some of the received messages are test calls.
8. A method of transmitting messages according to claim 7, in which where the first unit is a subscriber unit, test calls do not involve the user of the subscriber unit.
9. A method of transmitting messages according to claim 7 or claim 8, in which test calls are made sufficiently frequently to keep the transmit power of a subscriber unit at an optimum level.
10. A method of transmitting messages according to any of claims 7 to 9, in which the test calls are made at any or all of the RF carrier frequencies available to a subscriber unit.
11. A method of transmitting messages according to any of claims 7 to 10, in which test calls are made upon installation of the subscriber unit in the network.
12. A method of transmitting messages according to any of claims 7 to 11, in which second units are categorised according to propagation characteristics which they experience, and the frequency of test calls applied in determining whether power adjustments are required is selected dependent on the categorisation given.

13. A method of transmitting messages according to claim 1, in which at the start of a call the power level of transmission is set by the first unit dependent upon information of the power levels of the previous successful calls.
14. A method of transmitting messages according to any preceding claim, in which a power level adjustment to decrease the power level of transmission is only made provided interference is below a predetermined threshold.
15. A method of transmitting messages according to any preceding claim, in which transmissions are by radio.
16. Apparatus comprising a first transmitting and receiving unit and a second transmitting and receiving unit operative to transmit messages therebetween in predetermined time slots within fixed length time frames in which during a call a target power level of transmission is set by the second unit, the second unit is operative to measure the power level of a received message and to send a power level control signal to the first unit to adjust the power level of transmission during the call, the control signal being dependent upon the measured power level, and in which setting means are provided to set the power level of messages sent by the first unit at the start of a call dependent upon the adjusted power levels of messages sent by the first unit in previous successful calls to the second unit.
17. Apparatus according to claim 16, in which the first unit is a base station, and the second is one of a plurality of subscriber units.

18. Apparatus according to claim 16 or claim 17, in which subscriber units are at fixed locations.

19. Communication means comprising a base station and a plurality of subscriber units, the base station communicating with each subscriber unit by sending and receiving messages in predetermined time slots within fixed length time frames, in which during a call a target power level of transmission is set by the base station, the base station is operative to measure the power level of a received message and to send a power level control signal to the subscriber unit to adjust the power level of transmission during the call, the control signal being dependent upon the measured power level, and in which power level for messages sent by a subscriber unit at the start of a call is set dependent on the adjusted power levels of messages previously sent by that subscriber unit and received by the base station.

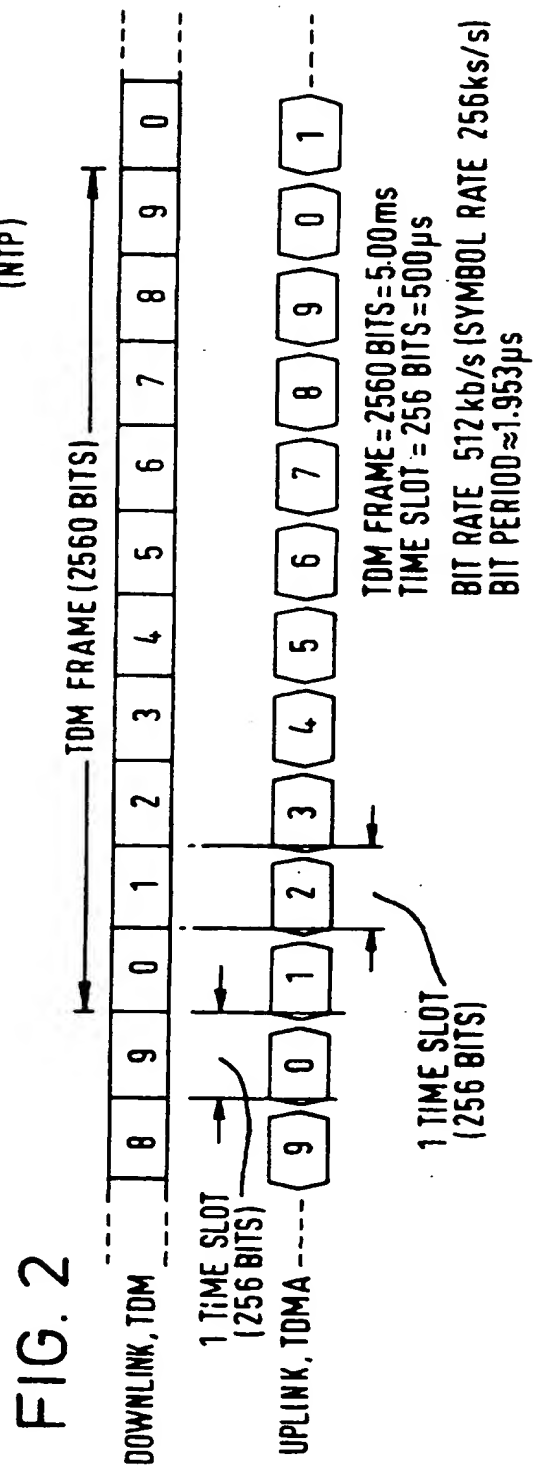
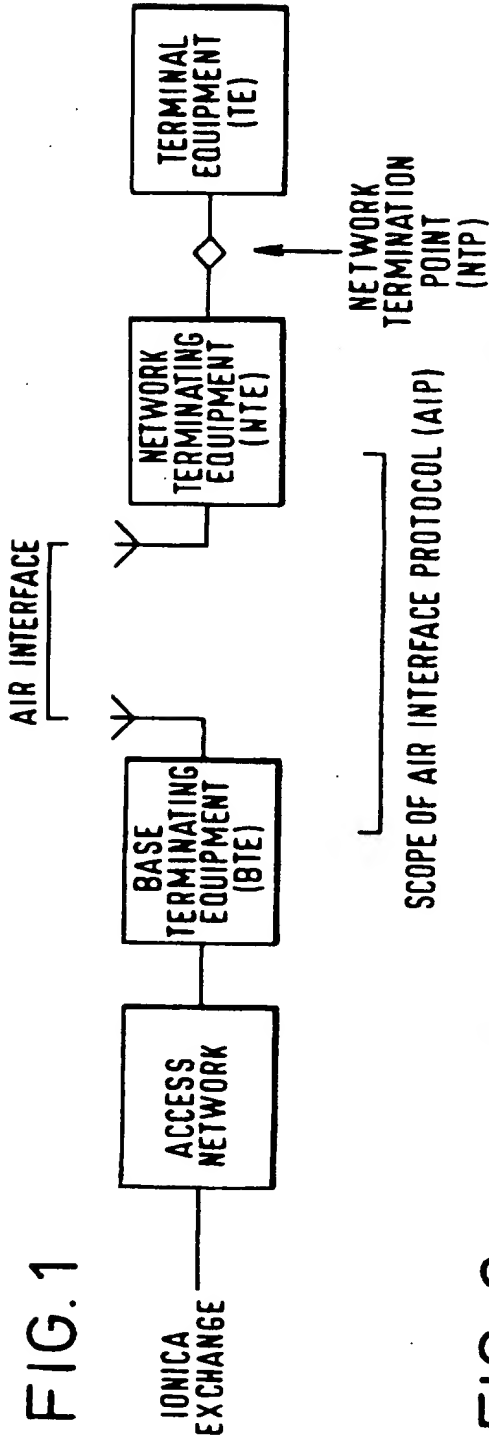
20. A method of transmitting messages in predetermined time slots within fixed length time frames between a first transmitting and receiving unit and a second transmitting and receiving unit in which the second unit is operative to measure the power level of a received message and to determine the level of interference due to other second units communicating with first units, said second unit being operative to send a power level adjustment signal to the first unit dependent upon the measured power level, to increase or decrease the power level, a power decrease signal being sent and/or a power decrease being effected provided the interference level is determined as being below a predetermined threshold.

21. Apparatus comprising a first transmitting and receiving unit and a second transmitting and receiving unit operative to transmit messages therebetween in predetermined time slots within fixed length time frames, in which the second unit is operative to measure the power level of a received message and to determine the level of interference due to other second units communicating with first units, said second unit being operative to send a power level adjustment signal to the first unit dependent upon the measured power level, to increase or decrease the power level, a power decrease signal being sent and/or a power decrease being effected provided the interference level is determined as being below a predetermined threshold.

22. Apparatus according to claim 21, in which the first unit is a subscriber unit, and the second unit is a base station.

23. Communication means comprising a base station and a plurality of subscriber units, the base station communicating with each subscriber unit by sending and receiving messages in predetermined time slots within fixed length time frames, in which the base station is operative to measure the power level of a received message from a subscriber unit and to determine the level of interference due to other base stations communicating with subscriber units, the power levels for messages sent by said subscriber unit being reduced dependent on the power level of the received message provided the level of interference is below a predetermined threshold.

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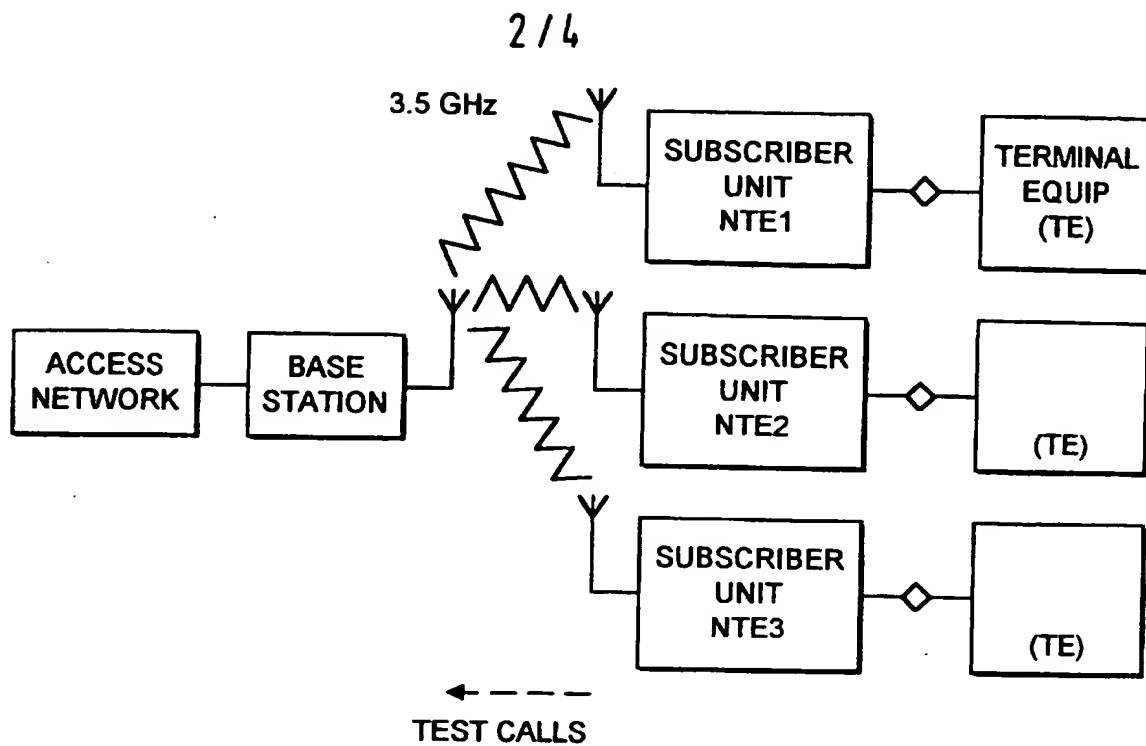


FIG. 3

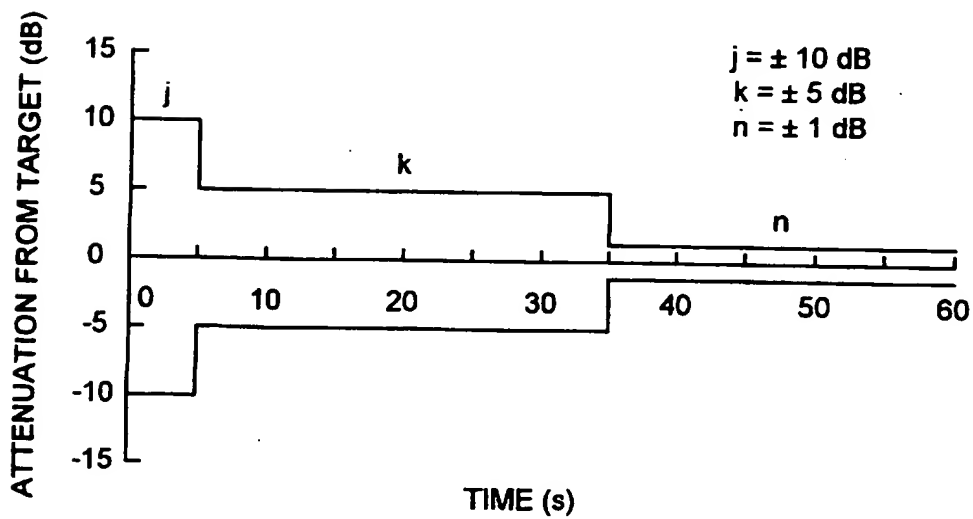
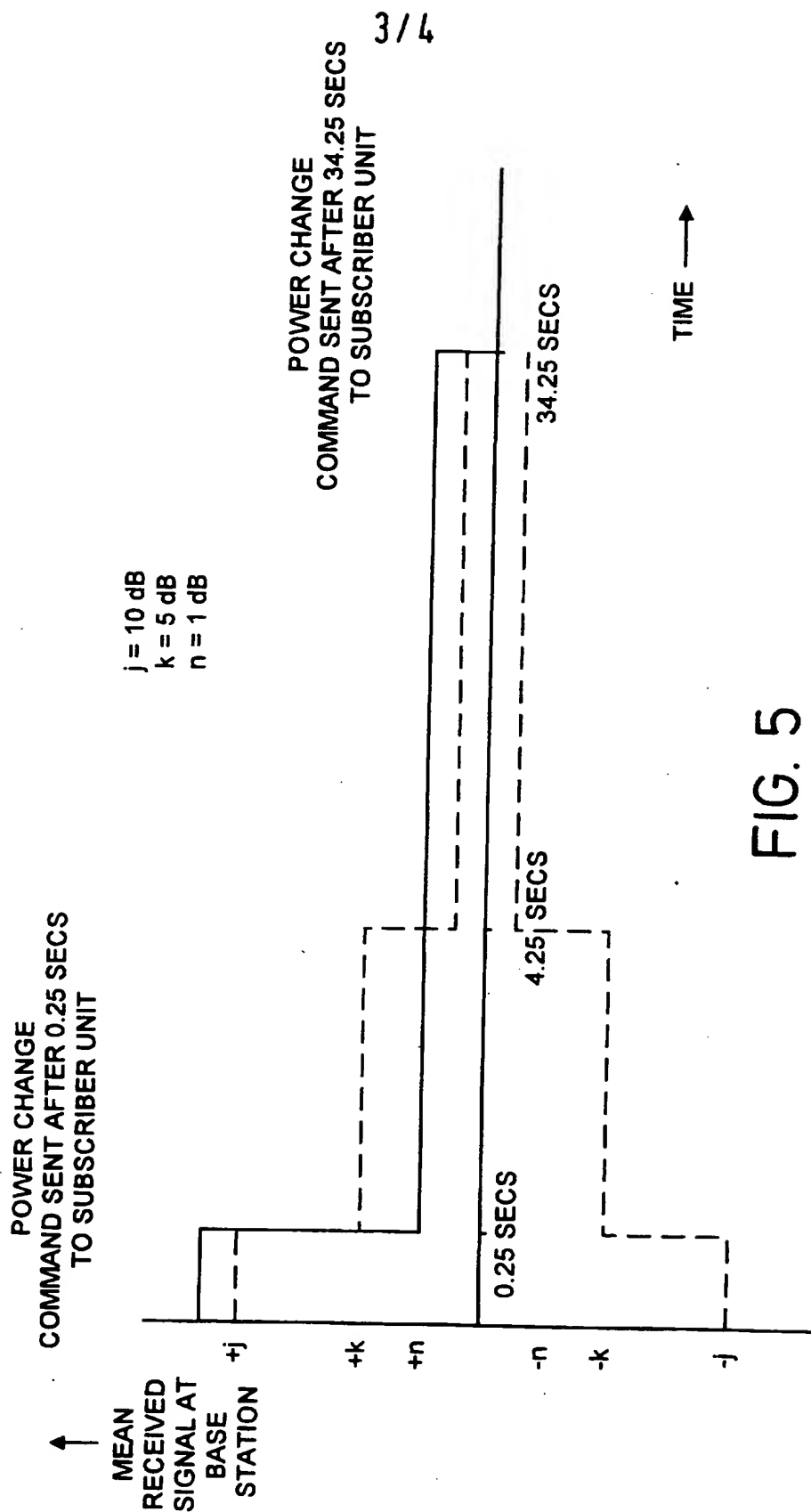


FIG. 4



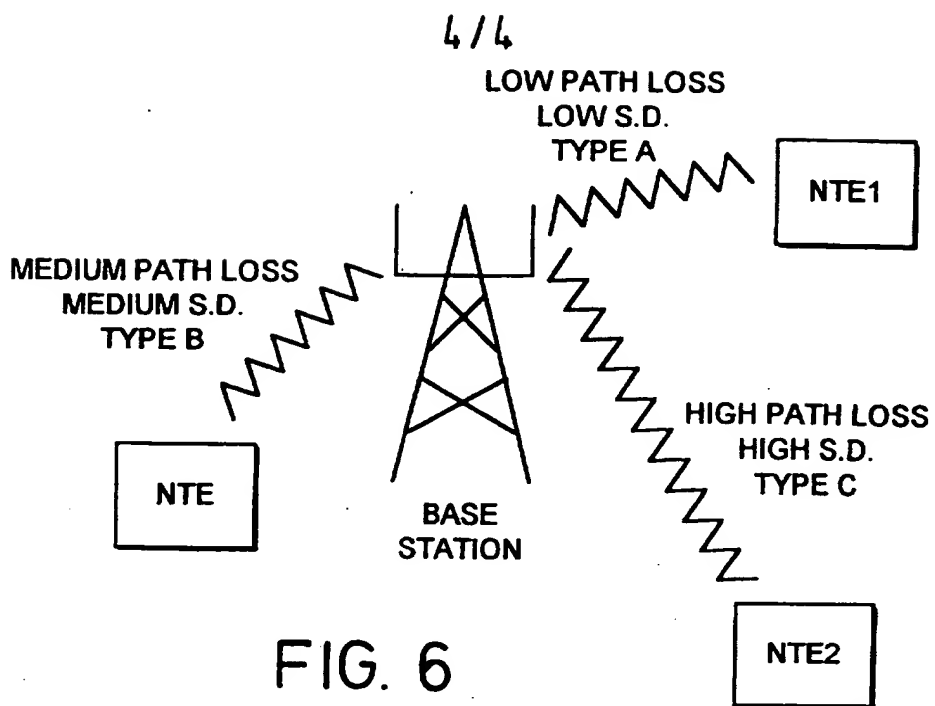


FIG. 6

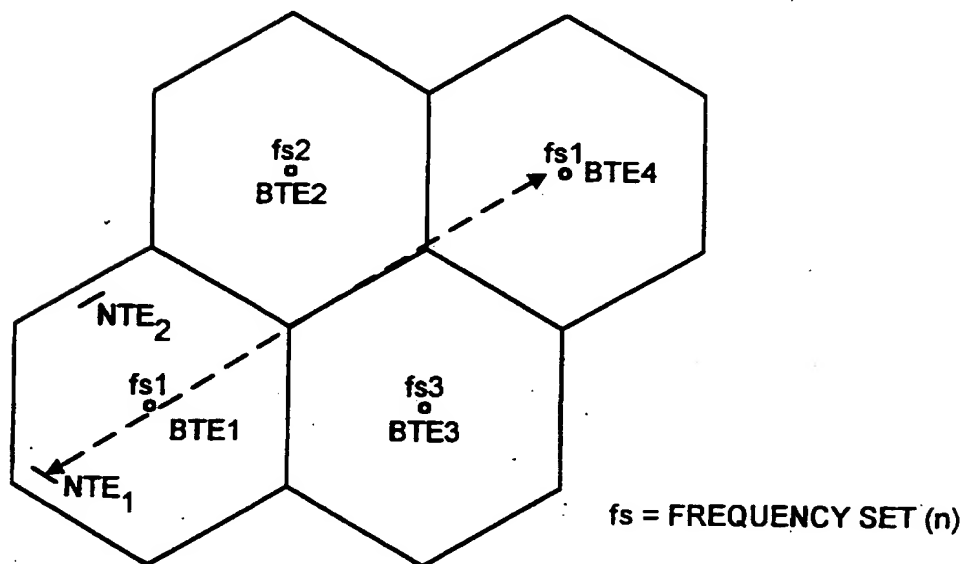


FIG. 7